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## ORIGINAL ARTICLE

# Traffic and industrial activities around Riyadh cause the accumulation of heavy metals in legumes: A case study



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**Abstract** The objective of this study was to analyse the effect of the continuously increasing anthropogenic activities around Riyadh, Saudi Arabia on the accumulation of heavy metals in leguminous crops. This study determined whether four legume crops, *Pisum sativum* L., *Vicia faba* L., *Glycine max* and *Vigna sinensis*, could accumulate the heavy metals Cu, Mn, Pb and Zn in their leaves, pods and grains during the summer when grown under conditions with ambient air pollution from heavy traffic and industrial activities in Riyadh, Saudi Arabia. The effect of the air pollution was examined by quantifying the protein and trace element Cu, Mn, Pb and Zn concentrations in the leaves, pods and grains of the four plant species. Analysis of the results indicated that air pollution significantly increased the heavy metal concentrations in the leaves, pods and grains. Toxic concentrations of the heavy metals were found in the plants grown at L3, L4 and L5. In conclusion, the air pollution increases as the traffic, industrial activities and population density increase.

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## 1. Introduction

Globally, atmospheric pollution is one of the major problems in urban environments, affecting human health as well as plants and microorganisms. Because of the high toxicity of heavy metals, heavy metal pollution affects crop growth and

the quality of agricultural products and also poses serious threats to human health through contamination of the food chain (Zhuang et al., 2009).

The main sources of air pollution in urban areas are traffic and industrial activities. Pollutants containing heavy metals are released from many different anthropogenic sources, such as industry, the combustion of fossil fuels in vehicular traffic, and energy production. (Celik et al., 2005; Oliva and Espinosa, 2007). Vehicular traffic emissions are of great concern because they consist of gaseous pollutants, including nitric oxide, carbon monoxide, sulphur dioxide, hydrocarbons, fine and coarse particulate matter, such as diesel soot, and airborne particulate-bound trace metals and metals (Laschober et al., 2004). These pollution components may remain in the air for some

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time, but most are deposited in roadside soils and plant materials near the road. These toxins can also enter plants directly via rain and dust and be taken up from the soil through the root system (Jozic et al., 2009).

Heavy metals are naturally present in soils, but contamination comes from many local sources, such as industry, agriculture, combustion of fossil fuels, and road traffic (Simon et al., 2011). Industrial activity has polluted the soil with a variety of heavy metals, such as Cd, Cu and Zn, in areas that affect crop production (Sharma and Dietz, 2008). Farmaki and Thomaidis (2008) reported increased concentrations of the metals Pb, Cu, Zn, Pt and Pd in the urban environment, including the topsoil, highways and streets. Based on a spatial analysis, it was determined that areas with highly elevated metal concentrations were generally located in industrial and residential areas, roadsides and crowded commercial districts (Li et al., 2004; Lee et al., 2006; Cicchella et al., 2008).

Some authors found high concentrations of trace metals in plants grown in polluted areas. For example, Celik et al. (2005) reported that the concentrations of Fe, Pb, Cu and Mn in roadside plants were approximately four times higher than in plants at control sites. Klumpp et al. (2009) found a significant accumulation of Pb and Cu in plants from traffic-exposed sites in city centres or close to major roads and moderate to low levels of accumulation in plants at suburban or rural sites.

Heavy metals can be classified as either potentially toxic or most likely essential. Toxic metals can be very harmful even at low concentrations when ingested over a long period of time (Unak et al., 2007). Essential metals can also produce toxic effects when the metal intake is excessively increased (Gopalani et al., 2007). Heavy metal toxicity in plants results in chlorosis, weak plant growth and decreased crop yield and may be accompanied by reduced nutrient uptake and plant metabolism disorders (Dan et al., 2008).

The rapid urbanisation and industrialisation that has occurred in Saudi Arabia has been accompanied by environmental changes caused by heavy traffic and industrial activities, particularly in Riyadh city. Legume pods and grains are rich in protein and are therefore widely used as protein sources for humans and animals (Munier-Jolain et al., 2008). This study was thus designed to assess the concentrations of several heavy metals in the edible portions and leaves of four legumes crops under conditions of urban air pollution. The results of this study may be important to increasing understanding of the levels of air pollution in the Riyadh area using crops.

## 2. Materials and methods

### 2.1. Experimental site and plant materials

The study was performed in Riyadh city (latitude 19°30', 7°30'N, longitude 42° and 48°E', 600 m above mean sea level). The average temperature varied from a minimum of 7 °C to a maximum of 26 °C, the average relative humidity varied from 10% to 50% and the total rainfall was 20.1 mm during the study period. The sampling sites in Riyadh were located from the northwest to the southeast to represent a gradual density of populated areas, traffic during most of the day, high buildings that limit wind circulation and industrial activities. An area without a direct source of pollution away from the city centre was used as the control site (Dirab) (Table 1).

The plants tested during the winter season were *Pisum sativum* L. and *Vicia faba* L., and the plants tested during the summer season were *Glycine max* and *Vigna sinensis*. The seeds (15) were sown in 40 cm plastic pots with a mix of 50% clay and 50% sand, and the pH was adjusted to 8.4. After germination, five uniform plants per pot were selected, and 10 pots for each species were transferred to each experimental site. The winter plants were exposed for consecutive periods of three months to ambient air during the winter, and the summer species were exposed during the summer.

### 2.2. Analysis of heavy metal concentrations

After the plants were harvested and washed, the leaves, pods and grains were then dried at 60 °C. The samples (0.5 g) were digested with concentrated HNO<sub>3</sub> and HClO<sub>4</sub> in a Teflon Digestion Vessel (Savillex, USA). The Cu, Mn, Pb and Zn concentrations were measured three times with an inductively coupled plasma-atomic emission spectroscopy (Perkin-Elmer Optima 4300 DV, USA) using three different samples at the Korean Basic Science Institute according to the method of Kim et al. (2005).

### 2.3. Statistical analysis

The statistical analyses used are as follows: ANOVA was used to test the effect of the sampling locations, and LSD was used for the mean separation. The generalised linear model (GLM) was used to test for interactions between the species and the sampling locations. All of the statistical analyses were performed with the SAS statistical package.

## 3. Results

### 3.1. Trace metal concentrations in the leaves, pods and grains of the winter crops (*P. sativum* and *V. faba*) and summer crops (*G. max* and *V. sinensis*)

The concentrations of copper, manganese, lead and zinc in the leaves, pods and grains of *P. sativum*, *V. faba*, *G. max* and *V. sinensis* are shown in Tables 2–5. The mean value of each location revealed differences in the accumulation of all of the metals studied, particularly in the polluted locations compared to the control.

#### 3.1.1. Copper (Cu)

There were no significant differences in the Cu concentration in the plant leaves except in summer crops at L5 sampling location where it was 1.660 mg g<sup>-1</sup> in *G. max* and 1.327 mg g<sup>-1</sup> in *V. sinensis* as compared to the control, L1 (Table 2). Moreover, there was a significant accumulation of Cu in the pods and grains of the winter crops at L4 and L5, while at L2, L3 and L4 in summer crops. Out of the four plants *G. max* contained the highest Cu content in the leaves at L5 sampling location.

#### 3.1.2. Manganese (Mn)

There were significant differences in the Mn concentrations in the leaves, pods and grains of both summer and winter plants except for pods of winter crops which showed no significant

**Table 1** Traffic density and industrial activities in experimental sampling locations.

Sampling location no.	Sampling location description	TD
L1	Control	Very low
L2	Low TD	122775
L3	High TD	946348
L4	Moderate TD density and Cement factory	115866
L5	Moderate TD density with high IA	115000

TD; Traffic density (average car daily), IA; industrial activity.

differences in the Mn concentrations at any location (Table 3). The highest Mn concentration in the leaves of *V. faba* occurred at L2, *P. sativum* at L3, *V. sinensis* at L5 and *G. max* at L4. High Mn concentrations were observed in the grains of winter crops (*P. sativum* and *V. faba*) at L2 and L4 respectively, whereas at L3 in summer crops compared to the control, L1.

### 3.1.3. Lead (Pb)

There were significant differences in the Pb concentrations in the leaves, pods and grains of all the four plants at all locations (Table 4). The highest Pb concentrations were recorded in the leaves, pods and grains of summer crops as compared to winter crops at all the sampling locations. The pods of *V. sinensis* contained the highest Pb concentration (46.12 mg/g) at L3 as compared with the other plants and sampling locations.

### 3.1.4. Zinc (Zn)

The concentration of Zn increased as the sources of air pollution increased in both winter and summer crops at all sampling

locations (Table 5). The plants of both winter and summer crops grown at L5 had the highest Zn concentrations in their leaves and pods, whereas the *V. faba* plants grown at L3 had the highest levels of Zn in their grains compared to the control location (L1). The plants of summer crops contained the highest concentrations of Zn at all the sampling locations with respect to the winter crops. Of all the four plants *V. sinensis* possessed the highest concentration of Zn at all the sampling locations with respect to control.

## 4. Discussion

The pods and grains of the *V. faba* plants grown at L4 and L5 contained the highest Cu concentrations, which were two and three times higher than those in the plants at the control location (0.103–0.108 mg g<sup>-1</sup> and 0.153 mg g<sup>-1</sup>, respectively). The Cu concentration in the *G. max* leaves at L5 was seven times greater (1.660 mg g<sup>-1</sup>) than that of the plants at the control location, and the Cu concentration in the *V. sinensis* leaves at L5 was more than five times greater than that of the plants at the control location. All of the plants that were grown in locations characterised by high traffic and high industrial activities (L4 and L5) accumulated high levels of Cu in their leaves, pods and grains. Under natural and anthropogenic conditions, the majority of the plant species can accumulate much more Cu (Kabata-Pendias and Pendias, 2001). The Cu concentrations in the aerial parts of these plants were at phytotoxic concentrations. According to Padmavathiamma and Li (2007), the phytotoxic concentration in plants is in the range of 20–100 mg kg<sup>-1</sup>. The highest Mn concentrations in the *V. faba* leaves were at L5, L2 and L3, whereas the highest Mn concentrations in the grains of plants were at L2, L3 and L4.

**Table 2** Effects of air pollution on the concentration of trace element (Cu; mg/g) in leaves, pods and grains.

Species	Sampling location	Leaves	Pods	Grains
<i>P. sativum</i>	L1	0.046 <sup>b</sup>	0.053 <sup>bc</sup>	0.043 <sup>c</sup>
	L2	0.044 <sup>b</sup>	0.058 <sup>bc</sup>	0.038 <sup>c</sup>
	L3	0.071 <sup>b</sup>	0.066 <sup>b</sup>	0.032 <sup>c</sup>
	L4	0.026 <sup>b</sup>	0.037 <sup>c</sup>	0.108 <sup>b</sup>
	L5	0.056 <sup>b</sup>	0.072 <sup>b</sup>	0.068 <sup>cd</sup>
<i>V. faba</i>	L1	0.043 <sup>b</sup>	0.052 <sup>bc</sup>	0.049 <sup>de</sup>
	L2	0.047 <sup>b</sup>	0.062 <sup>bc</sup>	0.033 <sup>c</sup>
	L3	0.241 <sup>a</sup>	0.071 <sup>b</sup>	0.07 <sup>c</sup>
	L4	0.068 <sup>b</sup>	0.103 <sup>a</sup>	0.153 <sup>a</sup>
	L5	0.065 <sup>b</sup>	0.108 <sup>a</sup>	0.153 <sup>a</sup>
Significant level		NS	**	***
<i>G. max</i>	L1	0.205 <sup>b</sup>	0.314 <sup>a</sup>	0.283 <sup>a</sup>
	L2	0.348 <sup>b</sup>	0.052 <sup>c</sup>	0.112 <sup>bc</sup>
	L3	0.174 <sup>b</sup>	0.043 <sup>c</sup>	0.124 <sup>bc</sup>
	L4	0.187 <sup>b</sup>	0.165 <sup>b</sup>	0.124 <sup>abc</sup>
	L5	1.660 <sup>a</sup>	0.139 <sup>bc</sup>	0.139 <sup>abc</sup>
<i>V. sinensis</i>	L1	0.206 <sup>b</sup>	0.068 <sup>c</sup>	0.031 <sup>c</sup>
	L2	0.346 <sup>b</sup>	0.084 <sup>c</sup>	0.082 <sup>c</sup>
	L3	0.175 <sup>b</sup>	0.104 <sup>c</sup>	0.044 <sup>c</sup>
	L4	0.336 <sup>b</sup>	0.044 <sup>c</sup>	0.042 <sup>c</sup>
	L5	1.327 <sup>a</sup>	0.039 <sup>c</sup>	0.086 <sup>c</sup>
Significant level		**	**	***

Level of significance: \* $p < 0.05$ ; \*\* $p < 0.01$ ; \*\*\* $p < 0.001$ ; NS: not significant. Mean values on each vertical column followed by the same letter do not differ significantly ( $P < 0.05$ ).

**Table 3** Effects of air pollution on the concentration of trace element (Mn; mg/g) in leaves, pods and grains.

Species	Sampling location	Leaves	Pods	Grains
<i>P. sativum</i>	L1	0.051 <sup>d</sup>	0.117 <sup>b</sup>	0.084 <sup>c</sup>
	L2	0.184 <sup>bcd</sup>	0.120 <sup>b</sup>	0.401 <sup>a</sup>
	L3	0.228 <sup>ab</sup>	0.129 <sup>b</sup>	0.343 <sup>a</sup>
	L4	0.125 <sup>cd</sup>	0.102 <sup>b</sup>	0.359 <sup>a</sup>
	L5	0.113 <sup>cd</sup>	0.399 <sup>a</sup>	0.218 <sup>b</sup>
<i>V. faba</i>	L1	0.052 <sup>d</sup>	0.134 <sup>b</sup>	0.020 <sup>c</sup>
	L2	0.340 <sup>a</sup>	0.174 <sup>b</sup>	0.340 <sup>a</sup>
	L3	0.329 <sup>ab</sup>	0.146 <sup>b</sup>	0.327 <sup>a</sup>
	L4	0.127 <sup>bcd</sup>	0.132 <sup>b</sup>	0.427 <sup>a</sup>
	L5	0.217 <sup>a</sup>	0.391 <sup>a</sup>	0.154 <sup>b</sup>
Significant level		**	NS	***
<i>G. max</i>	L1	1.358 <sup>ef</sup>	0.502 <sup>e</sup>	2.453 <sup>d</sup>
	L2	2.068 <sup>de</sup>	1.309 <sup>bc</sup>	2.611 <sup>d</sup>
	L3	3.387 <sup>b</sup>	1.633 <sup>bc</sup>	3.702 <sup>a</sup>
	L4	4.355 <sup>a</sup>	2.172 <sup>a</sup>	3.503 <sup>ab</sup>
	L5	2.137 <sup>de</sup>	2.401 <sup>a</sup>	2.804 <sup>cd</sup>
<i>V. sinensis</i>	L1	1.105 <sup>f</sup>	0.823 <sup>de</sup>	2.289 <sup>cd</sup>
	L2	2.531 <sup>cd</sup>	1.271 <sup>d</sup>	2.611 <sup>cd</sup>
	L3	3.318 <sup>b</sup>	1.700 <sup>bc</sup>	3.238 <sup>b</sup>
	L4	3.021 <sup>bc</sup>	1.650 <sup>bc</sup>	2.967 <sup>c</sup>
	L5	1.769 <sup>e</sup>	1.791 <sup>b</sup>	2.573 <sup>cd</sup>
Significant level		***	**	***

Level of significance: \* $p < 0.05$ ; \*\* $p < 0.01$ ; \*\*\* $p < 0.001$ ; NS: not significant. Mean values on each vertical column followed by the same letter do not differ significantly ( $P < 0.05$ ).

**Table 4** Effects of air pollution on the concentration of trace element (Pb; mg/g) in leaves, pods and grains.

Species	Sampling location	Leaves	Pods	Grains
<i>P. sativum</i>	L1	1.285 <sup>f</sup>	0.214 <sup>d</sup>	1.359 <sup>e</sup>
	L2	2.397 <sup>c</sup>	0.126 <sup>d</sup>	2.262 <sup>d</sup>
	L3	2.803 <sup>d</sup>	0.434 <sup>c</sup>	2.931 <sup>c</sup>
	L4	3.618 <sup>b</sup>	0.364 <sup>cd</sup>	3.651 <sup>b</sup>
	L5	4.029 <sup>a</sup>	0.620 <sup>bc</sup>	3.960 <sup>ab</sup>
<i>V. faba</i>	L1	1.198 <sup>f</sup>	0.251 <sup>d</sup>	1.470 <sup>e</sup>
	L2	2.152 <sup>e</sup>	0.184 <sup>d</sup>	2.207 <sup>d</sup>
	L3	3.001 <sup>cd</sup>	0.431 <sup>c</sup>	3.097 <sup>c</sup>
	L4	3.355 <sup>bc</sup>	0.359 <sup>cd</sup>	3.570 <sup>b</sup>
	L5	3.982 <sup>ab</sup>	0.843 <sup>a</sup>	4.123 <sup>a</sup>
Significant level		***	***	***
<i>G. max</i>	L1	5.624 <sup>gh</sup>	0.461 <sup>g</sup>	3.512 <sup>d</sup>
	L2	7.387 <sup>ef</sup>	25.538 <sup>de</sup>	6.032 <sup>b</sup>
	L3	8.707 <sup>de</sup>	35.331 <sup>b</sup>	7.626 <sup>a</sup>
	L4	9.353 <sup>cd</sup>	23.701 <sup>e</sup>	7.878 <sup>a</sup>
	L5	10.538 <sup>bc</sup>	34.602 <sup>b</sup>	8.152 <sup>a</sup>
<i>V. sinensis</i>	L1	5.014 <sup>h</sup>	0.104 <sup>g</sup>	3.031 <sup>d</sup>
	L2	6.775 <sup>fg</sup>	19.051 <sup>f</sup>	4.982 <sup>c</sup>
	L3	14.390 <sup>a</sup>	46.121 <sup>a</sup>	8.093 <sup>a</sup>
	L4	11.580 <sup>b</sup>	29.283 <sup>c</sup>	7.733 <sup>a</sup>
	L5	8.361 <sup>de</sup>	27.864 <sup>cd</sup>	8.251 <sup>a</sup>
Significant level		***	***	***

Level of significance: \* $p < 0.05$ ; \*\* $p < 0.01$ ; \*\*\* $p < 0.001$ ; NS: not significant. Mean values on each vertical column followed by the same letter do not differ significantly ( $P < 0.05$ ).

The Mn concentration in the *G. max* pods grown at L5 was four times higher than that in the pods of *P. sativum* and two times higher than that in the leaves of the control plants.

The highest Pb concentrations in the leaves and grains of the four genera were at L5, L4 and L3 compared to the control. The plants grown in all of the locations accumulated less

**Table 5** Effects of air pollution on the concentration of trace element (Zn; mg/g) in leaves, pods and grains.

Species	Sampling location	Leaves	Pods	Grains
<i>P. sativum</i>	L1	0.113 <sup>d</sup>	0.149 <sup>de</sup>	0.162 <sup>d</sup>
	L2	0.424 <sup>c</sup>	0.125 <sup>c</sup>	0.209 <sup>d</sup>
	L3	0.115 <sup>d</sup>	0.159 <sup>d</sup>	0.204 <sup>d</sup>
	L4	0.152 <sup>d</sup>	0.192 <sup>cd</sup>	0.763 <sup>c</sup>
	L5	1.135 <sup>b</sup>	0.235 <sup>b</sup>	0.929 <sup>c</sup>
<i>V. faba</i>	L1	0.214 <sup>cd</sup>	0.140 <sup>de</sup>	0.154 <sup>d</sup>
	L2	0.195 <sup>cd</sup>	0.690 <sup>cd</sup>	0.172 <sup>d</sup>
	L3	0.161 <sup>cd</sup>	0.143 <sup>de</sup>	2.724 <sup>a</sup>
	L4	0.164 <sup>cd</sup>	0.198 <sup>c</sup>	1.404 <sup>b</sup>
	L5	2.149 <sup>a</sup>	0.336 <sup>a</sup>	1.016 <sup>c</sup>
Significant level		***	***	***
<i>G. max</i>	L1	0.291 <sup>a</sup>	0.192 <sup>f</sup>	0.578 <sup>abc</sup>
	L2	0.267 <sup>a</sup>	1.013 <sup>e</sup>	0.691 <sup>ab</sup>
	L3	0.409 <sup>a</sup>	1.374 <sup>d</sup>	0.650 <sup>ab</sup>
	L4	0.298 <sup>a</sup>	1.601 <sup>c</sup>	0.672 <sup>ab</sup>
	L5	0.404 <sup>a</sup>	3.031 <sup>b</sup>	0.710 <sup>a</sup>
<i>V. sinensis</i>	L1	0.268 <sup>a</sup>	0.108 <sup>f</sup>	0.413 <sup>d</sup>
	L2	0.401 <sup>a</sup>	0.141 <sup>f</sup>	0.544 <sup>bc</sup>
	L3	0.336 <sup>a</sup>	1.063 <sup>c</sup>	0.470 <sup>c</sup>
	L4	0.404 <sup>a</sup>	1.090 <sup>c</sup>	0.451 <sup>c</sup>
	L5	0.415 <sup>a</sup>	5.43 <sup>a</sup>	0.473 <sup>c</sup>
Significant level		NS	***	*

Level of significance: \* $p < 0.05$ ; \*\* $p < 0.01$ ; \*\*\* $p < 0.001$ ; NS: not significant. Mean values on each vertical column followed by the same letter do not differ significantly ( $P < 0.05$ ).

Pb than the toxic dose according to Kabata-Pendias and Pendias (2001), which is in the range of 30–300 mg g<sup>-1</sup>. However, *P. sativum* and *V. faba* at L3, L4 and L5 accumulated toxic concentrations of Pb in their leaves and grains according to Markert (1994), who set the toxic dose for Pb in plants between 3 and 20 mg g<sup>-1</sup>. The winter plants had Pb pollution in locations L2, L3, L4 and L5 through the accumulation of toxic Pb concentrations (> 30 mg g<sup>-1</sup>) in their leaves and grains according to Markert (1994). Toxic Pb concentrations were observed in the pods of plants grown at L3 according to Kabata-Pendias and Pendias (2001). All of the plant species grown at L5 had the highest Zn concentrations in their leaves and pods, whereas the *V. faba* plants grown at L3 had the highest levels of Zn in their grains compared to the control location L1. *V. sinensis* grown at L2 had the highest grain Zn concentrations as compared to the control plants. The Zn concentrations in all of the aerial parts of the four species grown at L2 to L5 were within the toxic range set by Padmavathiamma and Li (2007). Normal concentrations of Zn in plants are in the range from 10–150 mg kg<sup>-1</sup>. The plants grown in locations with high traffic density and high industrial activities accumulated large amounts of Cu, Mn, Pb and Zn in their aerial parts compared to plants in the control location. These results were consistent with Celik et al. (2005), who reported Fe, Pb, Cu and Mn concentrations in roadside plants that were approximately four times greater than those in plants at control sites. Klumpp et al. (2009) found a significant accumulation of Pb and Cu in plants from traffic-exposed sites in city centres and close to major roads and moderate to low levels in plants that were exposed at suburban or rural sites. The trace metal concentrations in the pods and grains of both species were lower than the leaf concentrations. This may be because the seed is well protected from various stresses (Li

et al., 2004). Angelova et al. (2003) reported that the heavy metal accumulation in the seeds of leguminous crops grown at 0.1 and 15 km from a pollution source was considerably lower than it was in the roots and leaves.

Based on the concentrations of the heavy metals in the aerial parts of the four plants and on the sources of air pollution and heavy metals in Riyadh city that are caused by traffic and industrial activities, the plants grown near industrial complexes and heavy traffic areas had the highest heavy metal concentrations in their leaves, pods and grains. Many studies have confirmed that vehicle emissions are a significant source of heavy metals, particularly the traffic-related metals Pb, Cu and Zn (Akhter and Madany, 1993; Omar et al., 2007). Intense road traffic is responsible for large emissions of traffic-related air pollutants (Oliva and Espinosa, 2007). Based on the spatial analysis, it was found that areas with highly elevated metal concentrations were generally located in industrial and residential areas, roadsides and crowded commercial districts (Li et al., 2004; Lee et al., 2006; Cicchella et al., 2008).

## 5. Conclusion

The results of this study indicate that the level of ambient air pollution in terms of heavy metal emissions is of great concern in Riyadh city. The levels of the heavy metals Cu, Mn, Pb and Zn that accumulated in the plant materials clearly showed that the air pollution increased as the traffic density and industrial activities increased.

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